

LA-UR- 01-3397
c.2

Approved for public release;
distribution is unlimited.

Title: Ultrafast time-resolved 2D spatial interferometry for shock
wave characterization in metal films

Author(s): K.T. Gahagan, J.H. Reho, D.S. Moore, David J. Funk, and
R.L. Rabie

Submitted to: 12th APS Topical Conference on Shock Compression of
Condensed Matter, 24-29 June, 2001, Atlanta, GA



Los Alamos

NATIONAL LABORATORY

Los Alamos National Laboratory, an affirmative action/equal opportunity employer, is operated by the University of California for the U.S. Department of Energy under contract W-7405-ENG-36. By acceptance of this article, the publisher recognizes that the U.S. Government retains a nonexclusive, royalty-free license to publish or reproduce the published form of this contribution, or to allow others to do so, for U.S. Government purposes. Los Alamos National Laboratory requests that the publisher identify this article as work performed under the auspices of the U.S. Department of Energy. Los Alamos National Laboratory strongly supports academic freedom and a researcher's right to publish; as an institution, however, the Laboratory does not endorse the viewpoint of a publication or guarantee its technical correctness.

Ultrafast time-resolved 2D spatial interferometry for shock wave characterization in metal films

K.T. Gahagan¹, J. H. Reho², D.S. Moore², D. J. Funk², R.L. Rabie²

¹*Corning, Incorporated, Corning, NY 14831*

²*Dynamic Experimentation Division, Los Alamos National Laboratory, Los Alamos, NM 87545*

Abstract. We discuss the application of ultrafast time-resolved two-dimensional interferometric microscopy to the measurement of shock wave breakout from thin metal films. This technique allows the construction of a two-dimensional breakout profile for laser generated impulsive shocks with temporal resolution of < 300 fs and out-of-plane spatial resolution of 1.5 nm using 130 fs, 800 nm probe pulses. Constraints placed on the spatial extent of the probe region and on the spatial resolution of the technique by the short duration of the probe pulses will be discussed. In combination with other techniques, such as spectral interferometry, this technique provides a powerful means of investigating shock dynamics in a variety of materials.

INTRODUCTION

The advent of tabletop amplified ultrafast sources has opened the door to new methods of probing the dynamics of surfaces under extreme conditions. In particular, new insights are emerging into the behavior of materials under shock loading conditions on picosecond and femtosecond timescales (1-5).

A new spectroscopic method, frequency-domain interferometry (2-5), has been shown to provide detailed information about the dynamic optical properties and pressure profile of laser-generated pico-shocks propagating in metal thin films. This technique involves imaging the surface onto the entrance slit of an imaging spectrograph and analyzing the resulting spectral content. As such, a line profile through the shock breakout region is obtained. In a typical measurement a time profile of the shock breakout event is built up from many repeated measurements, while precisely adjusting the time delay between the shock generating pulse and the probe pulses. Pointing instability and beam

walkoff during the experiment can cause the line profile to intersect the shock profile at different points during the course of the experiment. In addition, the line profile does not provide detailed information about parameters such as shock tilt, or hot spots that a two dimensional image might provide.

To this end, we have developed a complementary technique to provide a two-dimensional image of shock breakout utilizing spatial interferometry with ultrafast pulses. We will describe the technique and its application to the study of shocked aluminium films. A trade-off between spatial resolution, noise and the temporal resolution of the measurement is discussed.

EXPERIMENTAL

Thin aluminium films (250 μm nominal thickness) were vapor plated onto microscope slide cover slips as target samples. A single 800 nm, 130 fs (FWHM), 0.7 mJ laser pulse generated by a

seeded, chirped pulse amplified Ti:sapphire laser system (Spectra Physics) was used for both shock-generation and probing. The shock generating pulse (0.2 – 0.5 mJ) was focused onto the front side of the target assembly to a spot size of 75 μm . A small portion of the main pulse (~ 0.04 mJ) reflected from a beam splitter was passed through an interferometer with the sample in one arm and a variable delay to control temporal overlap in the other. The probe pulse was focused onto the backside of the target at an angle of $\sim 32.6^\circ$ to a spot size of ~ 200 μm to circumscribe the region of shock break out. The probe pulse was s-polarized relative to the plane of incidence. An imaging lens and a duplicate in the reference arm were used to image the surface and reference beam onto a CCD camera (Photometrics). The interferogram was stored and processed in real time. The experimental arrangement is shown schematically in Fig. 1.

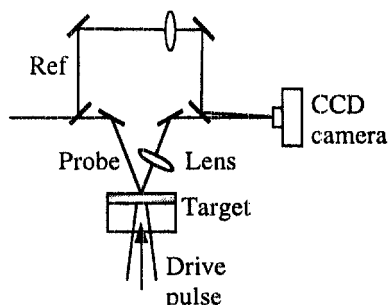


Figure 1. Schematic diagram of the femtosecond laser-driven shock/spatial interferometry experiment on thin film aluminium samples.

The thin film targets were mounted on a computer-controlled x-y translation stage. The target was rastered at 300 μm intervals between experiments so that each laser-driven shock would propagate into undisturbed material.

The 1024 x 1536 camera (9 μm pixel pitch) was arranged with the 1024 height dimension perpendicular to the interference fringes. The interference angle was adjusted to give approximately 3.5 pixels per fringe, corresponding to an angle of ~ 25 mrad. Under these conditions, we found that it was not possible to achieve uniform full depth fringes over the entire 1 cm high

array. This results from the fact that the temporal confinement of the pulse reduces the effective overlap of the fields near the edges of the images. This was confirmed by adjusting the time delay between the reference and probe leg. We observe that the region of best contrast would shift from one side of the interferogram to the other as the temporal overlap of the pulses shifted. In order to improve this condition, we narrowed the bandwidth of the seed laser to achieve a ~ 170 fs (FWHM) pulsewidth. Note that simply adjusting the pulse compressor to vary the pulsewidth did not achieve the desired end. This suggests a fundamental tradeoff between the pulse bandwidth (or minimum pulse duration) and the spatial carrier frequency of the pattern for a given image height.

Using this apparatus a series of interferograms was acquired before and during shock wave breakout. Two-dimensional Fourier analysis was used to separate the carrier frequency contribution to construct a phase and amplitude of the probe pulse. A region surrounding the breakout region was used to perform a two-dimensional background subtraction to remove instrumental artifacts. And finally, to obtain a phase shift associated with surface motion and refractive index dynamics, the central portion of the phase in the shock breakout region was averaged over a 40 μm diameter central area. This result can then be directly compared with phase shifts vs. time measured with spectral interferometry.

RESULTS

A series of phase images corresponding to different time delays is shown in Figure 2. Before breakout, a slight positive phase shift is observed. This phase shift is constant over a long time period (at least 20 ps) prior to breakout suggesting a fast process (electron or x-ray preheating) as an origin. We are currently investigating this effect further. As the shock wave nears the surface, we observe a negative phase shift, first as a ring pattern near the periphery of the shock and then throughout. This negative shift is consistent with spectral interferometry profiles and is believed to be associated with refractive index dynamics. Later in time, the surface motion dominates the phase and a

positive shift is observed. It is clear from the later

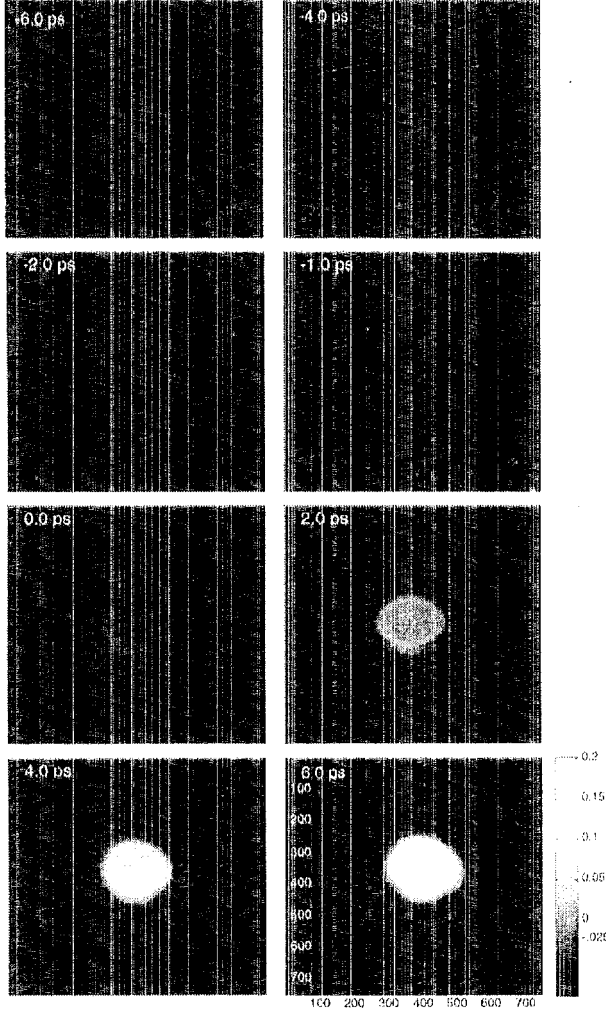


Figure 2. Images of the interferometric phase of a 250 nm Al film during various stages of shock breakout

time images that the shock wave is slightly tilted from top to bottom. An analysis of this tilt reveals that it is on the order of 3-4 nm over 75 μm or 40 μrad .

Figure 3 plots the phase, averaged over the central region of the shock as a function of time. Previous analysis from spectral interferometry has shown that the refractive index change is very nearly linearly proportional to the acceleration of the surface. Using these assumptions, we have plotted a phase due to optical dynamics and a phase due to

surface motion on the same graph. Note that the long time behavior, where the surface appears to decelerate gradually, was not used in the fitting of these curves. The noise level of the raw data shows a phase sensitivity of ~ 3 mrad, or 5 Angstroms of surface displacement. The 10%-90% rise time of the pressure profile is estimated at 3.7 ps with a final free surface velocity of 0.6 nm/ps.

For direct comparison, both the spatial interferometry technique described here and a spectral interferometry measurement were performed on the same sample (not shown). The resulting phase was observed to be identical within the noise limits of the measurements, verifying the consistency of the techniques.

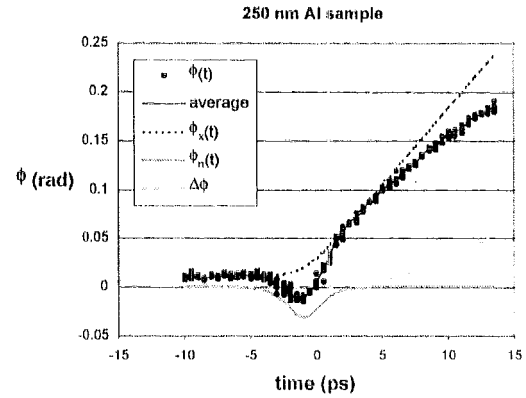


Figure 3. Phase vs. time of shock breakout from a thin Al film. Dots represent raw shot-to-shot data. $\phi_s(t)$ and $\phi_r(t)$ are the contributions to the phase of the surface displacement and refractive index respectively

DISCUSSION

An intriguing feature of the phase profile during breakout is the ring structure of the negative phase shift as the shock wave emerges from the surface. In addition, some profiles show a set of concentric rings. These rings may be related to surface electronic waves created by the shock disturbance at the boundary between shocked and unshocked material. We do not see a consistent growth or motion of these waves with time.

The technique clearly has application to complement spectral interferometry and other techniques for probing picosecond shock waves for the timescales presented here. Probing at shorter timescales, however, will require limiting the spatial extent of the image area or sacrificing spatial resolution.

ACKNOWLEDGEMENT

This research was performed under the auspices of the US Department of Energy.

REFERENCES

1. Tas G., Franken J., Hambir S.A., Dlott D.D., Phys. Rev. Lett. 78, 4585 (1997)
2. Tokunaga E., Terasaki A., and Kobayashi T., Opt. Lett. 17, 1131 (1992)
3. Geindre J.P., Audebert P., Rousse A., Fallières F., Gauthier J.C., Mysyrowicz A., Dos Santos A., Hamoniaux G., and Antonetti A., Opt. Lett. 19, 1997 (1994)
4. Evans R., Badger A.D., Faillières F., Mahdiah M., Hall T.A., Audebert P., Geindre J.-P., Gauthier J.-C., Mysyrowicz A., Grillon G., and Antonetti A., Phys. Rev. Lett. 77, 3359 (1996).
5. Gahagan, K.T., Moore, D.S., Funk, D.J., Rabie, R.L., Buelow, S.J., Nicholson, J.W., Phys. Rev. Lett. 85, 3205 (2000).